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**THESIS NO: 073/MSMS/859**

**Arsenic Removal from Water by Adsorption onto Iron oxide/Activated Carbon Composite Prepared from Giant Reed**

By

Manobin Sharma

A THESIS

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DEGREE OF MASTER IN MATERIAL SCIENCE AND ENGINEERING

DEPARTMENT OF APPLIED SCIENCES AND CHEMICAL ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Arsenic Removal from Water by Adsorption onto Iron oxide/Activated Carbon Composite Prepared from Giant Reed " submitted by Manobin Sharma in partial fulfillment of the requirements for the degree of Master in Material Science and Engineering.

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# Abstract

Groundwater in the southern low land region of Nepal has been recognized as a major problem due to Arsenic contamination. Therefore, the present study aimed to remove arsenic from the water using iron/activated carbon composite prepared from Giant Reed cane (*Arundo donax*). Activated carbon (AC) was prepared by chemical activation with zinc chloride at 400°C in ratio 1:1 by weight for 3 hrs. The resulting AC was composited with iron oxide particles, using facile hydrothermal treatment to improve its adsorption capacity for arsenic removal from water. Both, activated carbon and its composite adsorbent were characterized by scanning electron microscopy (SEM) and Energy Dispersive X-ray analysis (EDX). Results showed the presence of some iron oxide particles dispersed on the activated carbon. Batch adsorption experiments were conducted for the adsorption of As (III) onto the composite adsorbent. The experiment included the effect of process variables viz. contact time, pH, adsorbent dose, and adsorption isotherm. The obtained results showed that the percentage of As (III) removal using the composite adsorbent was much higher as compared to the plain AC. The optimum conditions for As (III) adsorption were achieved at pH 8, adsorbent dosage 1.8 g/L, and contact time 60 minutes. Adsorption data fits Langmuir better than Freundlich isotherm which indicates that the monolayer adsorption of As (III) onto the composite adsorbent. The maximum As (III) adsorption capacity of the composite adsorbent was 16.34 mg/g. Therefore, it can be concluded that the AC composite derived from Giant Reed cane can be potentially applied for the removal of As (III) from contaminated water.

Keywords: Giant Reed, activated carbon, composite, arsenic, adsorption.

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# List of abbreviations and symbols

AC activated carbon

As arsenic

As(III) arsenite

As(V) arsenate

AsH3 arsine

As2O3 arsenic trioxide

C carbon

CO2 carbon dioxide

EDX Energy Dispersive X-ray analysis

EU European Union

SEM Scanning Electron Microscopy

g/l gram per liter

HCl Hydrochloric acid

HFO hydrous ferric oxide

H2SO4 sulphuric acid

H3PO4 phosphoric acid

 **List of abbreviations and symbols**

IR infrared

KOH potassium hydroxide

ltr liter

ml milliliter

mg milligram

NH3 Ammonia

nm nanometer

NP nanoparticle

ppm parts per million

ppb parts per billion

PVP polyvinylpyrrolidone

ZnCl2 zinc chloride

µg microgram

°C degree Celsius

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# CHAPTER ONE: INTRODUCTION

## Background

Arsenic is recognized as a highly toxic/poisonous element, found in nature which creates potentially serious environmental problems. Arsenic is present in groundwaters all over the world mostly Africa, Europe, North, and South America, Asia including Nepal as a natural and anthropogenic contaminant.

About 47% of the total population of Nepal lives in Terai (low land) region and 90% of them depend on groundwater as their primary source of drinking water. It is reported that groundwater of the Terai region is contaminated with arsenic (Shrestha *et al*., 2014). Around half a million of the population (inhabitants of Terai Region) are believed to have been exposed to arsenic levels greater than 50 μg/L, while 3.5 million are believed to have been exposed to arsenic levels between 10 to 50 μg/L (Pokhrel *et al*., 2009).

Arsenic exists in organic as well as inorganic forms with varying valence states, i.e., As (III), As (V), and As (0). The valence state of arsenic plays an important role in its behavior and toxicity in aqueous system and found in inorganic form as oxyanions of trivalent arsenite (As (III)) or pentavalent arsenate (As(V)). Chronic arsenic exposure has devastating health effects, viz, cardiovascular diseases, cancer, and eventual death. To minimize the risk of pollution problems from arsenic in water, it is necessary to treat contaminated water. The most widely used methods for removing arsenic from water include ion exchange, chemical precipitation, reverse osmosis, membrane filtration, and adsorption. Most conventional methods require high capital investment and are high in operational costs and create sludge disposal problems. Hence, the search for low cost and environmentally sound ways of treating contaminated water is becoming very important. For Arsenic ions of low concentration, adsorption is a much preferable technique to remove arsenic in wastewater. In this technique, different adsorbents are used to remove arsenic from water. The commonly used adsorbents are activated carbon, zeolite, activated alumina, silica gel, etc. Among these, activated carbon is one of the commonly used adsorbents in water treatment due to high surface area and porosity. But AC alone is not very effective when it comes to the removal of arsenic from water. Activated carbons modified by iron hydro (oxide) nanoparticles have quite recently been studied for As removal and were found efficient for the removal of arsenic at concentrations lower than 300 mg/L (Yao *et al*., 2014). AC can also act as a skeletal structure to support the fragile nature of granular iron media. The adsorption features of activated carbon and the magnetic properties of iron oxides are combined in a composite to produce adsorbent for better removal of arsenic. Thus, iron oxide loaded AC composite can be an active adsorptive material that can remove arsenite from the water with high adsorption capacities.

## Arsenic

Arsenic mainly occurs in the aqueous system in several oxidation states (−3, 0, +3, +5). There are two types of the arsenic compound present, inorganic arsenic, and organic arsenic compounds. Usually, inorganic arsenic is found more toxic than organic. In natural water, inorganic arsenic is mostly found as trivalent arsenite or pentavalent arsenate. The trivalent arsenic (Arsenite, As (III)) is more mobile and toxic (40-60 times) than the pentavalent arsenic (Arsenate, As (V)) (Mueller *et al*., 2018 and Jang *et al*. 2014). In surface water under oxidizing conditions, arsenate predominates while in anoxic water under reducing conditions, arsenite becomes stable. At near neutral pH, the predominant species are H2AsO4− and HAsO42− for arsenate, and uncharged H3AsO3 for arsenite (Mueller *et al*., 2019). Inorganic species of arsenic (As (III) and As (V)) represent a potential threat to the environment, human, and animal health due to their carcinogenic and other effects. Permanent arsenic intake can lead to chronic intoxication, and prolonged arsenic exposure can damage the central nervous system, liver, and skin and results in the appearance of diverse types of cancers, such as hyperkeratosis, lung, skin, and prostate cancers (Hong *et al*., 2014). Therefore, the removal of arsenic from drinking water is of importance.

## Arsenic Contamination in Nepal

As per data of today, at least 140 million people in 50 countries including Nepal have been drinking water containing arsenic. Specifically, in Southeast Asia, more than millions of people drink water with concentrations higher than the WHO guideline value of 10 µg/L (WHO, 2008).

About 47% of the total population of Nepal lives in Terai (low land) region and 90% of them depend on groundwater as their primary source of drinking water. In 1999 Department of Water Supply and Sewerage (DWSS) and the World Health Organization (WHO) identified Arsenic contamination in groundwaters of the Terai region. Around 20 districts of this region, including highly populated districts like Siraha, Sunsari, Dhanusha, Rupandehi, Kailali, etc. are contaminated with a high concentration of arsenic in groundwater (Pokhrel *et al*., 2009 and Shrestha *et al*., 2014). By recent studies within the Terai region, the presence of high concentrations of arsenic (>6.7 M) in alluvial aquifers is confirmed. Around half a million of the population (inhabitants of Terai Region) are believed to have been exposed to arsenic levels greater than 50 μg/L, while 3.5 million are believed to have been exposed to arsenic levels between 10 to 50 μg/L (Pokhrel *et al*., 2009).

## Arsenic removal technologies

Several arsenic removal methods such as chemical precipitation/flocculation (Safarik *et al*., 1997; Oliveira *et al*., 2002), adsorption/ion exchange (Banerjee *et al*., 2008; Sperlich *et al*., 2005), reverse osmosis (Yoon *et al*., 2009) and electro-dialysis (Imran *et al*., 2011) have been developed. In general, adsorption is considered to be more effective and efﬁcient than membrane ﬁltration. This technique has been quite popular in recent years, due to its simplicity as well as the availability of a wide range of adsorbents. Various adsorbents are used nowadays, like activated alumina, activated carbon (AC), silica gel, zeolites for the removal of arsenic. Removal of arsenic from contaminated water by adsorption onto iron oxides, metallic iron, or magnetic iron oxides has been reported by many researchers in the last decades (Gallios *et al*., 2017).

**Activated carbon (AC)**

Activated carbon (AC) is a carbonaceous material with a highly porous structure and large internal surface area. One of the main characteristics of AC is its adsorption capacity. The adsorption capacity of an adsorbent depends on its structural parameters such as surface area, pore size, pore-size distribution, pore-volume, and the presence of surface functional groups (Putra *et al*., 2017). Pores of AC are classified in three groups: micropores (width < 2 nm), mesopores (width = 2–50 nm), and macropores (width > 50 nm (IUPAC)). Activated carbons with highly developed surface area and porosity are widely used in a variety of industries for applications which include separation/purification of liquids and gases, super-capacitors, electrodes, gas storage, and so on.

**Activated carbon composite**

Composite material composed of two or more physically distinct phases whose combination produces a synergistic effect and aggregate properties that are different from those of its constituents. The carbon composites use carbon as the hosting matrix, taking advantage of unique mechanical, physical, and chemical properties of carbon and diverse morphologies such as activated carbon, fullerene (C60), CNFs, CNTs, expanded graphite, and graphene. Recently studies of composite particles have been attracting much attention due to its unique structure and properties. They represent an interesting and attractive alternative as adsorbents due to their high reactivity and excellent selectivity towards specific pollutant compounds. The applications of carbon composites expanded to a wide range of fields such as environmental treatment, microwave absorption, magnetic media, electrochemical sensor, catalysis, separation of biomolecules, drug delivery, etc. (Zhu *et al*., 2011). To introduce magnetic properties of composites, various metallic materials have been utilized including iron, nickel, and cobalt. Most studies have considered iron-based material due to their higher magnetic character and lower cost. The properties of the composite are determined both by their structure and the chemical nature of their surface. The most frequently used magnetic particle is iron oxide, especially magnetite and maghemite. Fe (III) has a high affinity for inorganic As species and selectively performs As sorption. Inner sphere surface complexion can explain the strong interaction between As (V) and various Fe oxides (Shokrollahi, 2017).

**The raw material for the preparation of AC**

The quality of the resulting activated carbon is considerably influenced by the raw material. Although the activation procedure employed mainly determines the chemical nature of the surface oxides and the surface area of the resultant product, the structure of the pores and the pore size distributions are largely predetermined by the nature of the starting material. Any cheap substance with high carbon and low ash content can be used as a raw material. Raw materials for the production of activated carbon include several carbonaceous materials, apricot stones, wood, peat, brown coal, bituminous coal, lignite, coconut shells, almond shells, pits from peaches and other fruit, petroleum-based residues, and pulp mill residues (Balc., 1992).

## Giant Reed

Giant reed (*Arundo donax*), is commonly known as Arundo donax L, belonging to the family Poaceae. It is a perennial rhizomatous grass native from eastern Asia, found growing spontaneously in various regions in many countries, like Portugal, Spain, and Brazil. In Nepal, it grows in wetlands and riparian natural surroundings from Kathmandu valley to the Koshi Tapu in the west. It is a promising grassy plant to be used as a renewable resource for the production of fuels and chemicals, because of its fast growth rate, ability to grow in different soil types and climatic conditions. The high productivity and low input requirements make it a promising feedstock for the production of chemicals and biofuels. Besides, it has great potential as a renewable precursor with a unique chemical composition for the preparation of activated carbons (ACs) with high-grades. ACs obtained from giant reed biomass has shown high performance for adsorption of organic and inorganic pollutants for wastewater treatment, thus solving environmental problems of waste disposal and pollution control (Muthanna J. Ahmed, 2016).

Figure 1: Giant Reed Plants

**Preparation of activated carbon**

AC is prepared by the process of carbonization in absence of air (usually in an inert atmosphere with gases like nitrogen and argon) followed by activation of the carbonized product (impregnation with or without chemicals). Carbonization helps in the formation of fixed carbon with basic pore structure and on activation, enlarges the diameter of the pores, and also creates new pores. There is two methods of activation: physical and chemical activation.

**Physical activation**

Physical activation involves carbonization of the precursor in an inert atmosphere and activation of resulting char by an activation agent such as steam, CO2, or air at high temperature. Since the rate of reaction between the activating agent (steam or CO2) and the char is low, a high temperature (>800 °C) for activation is necessary.

**Chemical Activation**

In chemical activation, the precursor is impregnated with a given chemical agent and pyrolyzed after that. As a result of the pyrolysis process, a much richer carbon content material with a much more ordered structure is produced, and once the chemical agent is eliminated after the heat treatment, the porosity is highly developed. Several activating agents have been reported for the chemical activation process: phosphoric acid, zinc chloride, potassium hydroxide, and alkaline metal compounds. Phosphoric acid and zinc chloride are activating agents usually used for the activation of lignocellulosic materials which have not been previously carbonized; while, alkaline metal compounds, usually KOH, are used for the activation of coal precursors or chars.

Chemical activation offers several advantages over physical activation as

* It is usually carried out in only one step
* Lower activation temperature
* High surface area (up to 3600 m2/g) and
* Microporosity can be very well developed with a well-controlled distribution.

**Activating agent**

The activating agent may promote the formation of cross-links, leading to the formation of a rigid matrix, less prone to volatile loss, and volume contraction upon heating to high temperatures. It can easily open up pores and cavity of the prepared AC to enhance their adsorption capability. Depending on the activating agent, its concentration, and the raw material, the carbon will possess a highly developed internal pore structure and be an effective adsorbent for molecules in the gas or liquid phase. The most commonly used agents for chemical activation are acidic reagents such as ZnCl2, H3PO4, HCl, and H2SO4 or the basic reagents KOH, K2CO3, NaOH, and Na2CO3.

## Hydrothermal Approach

Hydrothermal synthesis is a typical aqueous solution-based approach, which is usually employed under high temperature and pressure. In the early days, this process leads to the formation of various rocks and minerals. Nowadays, an artificial way is used to synthesize single-crystal (nanoparticles) from high-temperature aqueous solutions at high vapor pressures. Hydrothermal synthesis can occur in a water-based system and at a lower reaction temperature (160– 220 °C) in a relatively environment-friendly approach, unlike the thermal decomposition method, which can only use an organic compound as a solvent. Efforts are being dedicated to the controlled synthesis metal nanostructure by this approach because of their unique chemical and physical properties that are different from those of the bulk materials (Xu *et al*., 2006).

Carbonates, silicates, simple and complex oxides, etc. have been synthesized under hydrothermal conditions. The commonly hydrothermal process is applied for the production of quartz, gems like crystal that possesses high commercial value. The hydrothermal process, a single-step process can be used to give high product purity and homogeneity, crystal symmetry, narrow particle size distributions (sub-micron to nanoparticles with a narrow size distribution) with a wide range of chemical compositions. Also, this process is used for the growth of crystals with polymorphic modifications.

## Adsorption

Adsorption is the adhesion of atoms, ions, or molecules from a gas, liquid, or dissolved substance to a surface of a material. It is a surface phenomenon that occurs at gas-solid, gas-liquid, liquid-liquid, or liquid-solid interfaces. This process creates a film of the adsorbate the molecules or atoms being accumulated, on the surface of the adsorbent. The material on whose surface adsorption occurs is called adsorbent and the substance that deposits at the surface is called adsorbate. For example in the adsorption of arsenic on activated carbon, arsenic is the adsorbate and activated carbon is the adsorbent. Depending upon the nature of forces existing between adsorbate molecules and adsorbent, the adsorption can be classified into two types:

* **Physical adsorption (physisorption):** If the force of attraction existing between adsorbate and adsorbent are Vander Waal’s forces, the adsorption is called physical adsorption. It is also known as Vander Waal’s adsorption. In physical adsorption the force of attraction between the adsorbate and adsorbent is very weak, therefore this type of adsorption can be easily reversed by heating or by decreasing the pressure.
* **Chemical adsorption (chemisorption):** If the force of attraction existing between adsorbate and adsorbent is the almost the same strength as chemical bonds, the adsorption is called chemical adsorption. It is also known as Langmuir adsorption. In chemisorption the force of attraction is very strong, therefore adsorption cannot be easily reversed.

## Adsorption Isotherms

The adsorption process is usually studied through graphs known as adsorption isotherm. That is the amount of adsorbate on the adsorbent as a function of its pressure or concentration at a constant temperature. The isotherm indicates how molecules of adsorbate distribute between the solid and liquid phase when the adsorption process reaches an equilibrium state. The adsorption isotherm is the most important and extensively employed tool for representing adsorption equilibrium. The adsorption data can be expressed by several adsorption isotherms. The important adsorption isotherms which are generally used in water treatment are the Langmuir isotherm and the Freundlich isotherm.

**Freundlich Isotherm:** In 1909, Freundlich expressed an empirical equation for representing the isothermal variation of adsorption of a quantity of gas adsorbed by a unit mass of solid adsorbent with pressure. This equation is known as the Freundlich adsorption isotherm or Freundlich adsorption equation.

$\frac{x}{m}=kP^{\frac{1}{n}} $ (1)

Where,

 x/m = adsorption per gram of adsorbent which is obtained by dividing the amount of adsorbate (x) by the weight of the adsorbent (m). P is Pressure, k and n are constants whose values depend upon adsorbent and gas at a particular temperature.

Though Freundlich Isotherm correctly established the relationship of adsorption with pressure at lower values, it failed to predict the value of adsorption at higher pressure.

It can be expressed as follows in linear form,

  (2)

Where K= Freundlich constant, n = adsorption intensity

This model assumes that the uptakes of metal ions occur on a heterogeneous surface by multilayer adsorption and that the amount of adsorbate adsorbed increases infinitely with an increase in concentration.

**Langmuir Isotherm:** In 1916, Irving Langmuir published a new model isotherm for gases adsorbed to solids, which retained his name. It is a semi-empirical isotherm derived from a proposed kinetic mechanism. This isotherm was based on different assumptions one of which is that dynamic equilibrium exists between adsorbed gaseous molecules and the free gaseous molecules.

It is based on four assumptions:

1. The surface of the adsorbent is uniform, that is, all the adsorption sites are equivalent.
2. There is no interaction between adsorbate and adsorbent during the adsorption.
3. All adsorption occurs through the same mechanism.
4. Only a monolayer is formed on the homogenous surface of the adsorbent.

The Langmuir equation is given as:

 (3)

Where,

Ce = equilibrium concentration (mg/L)

qe = amount adsorbed under equilibrium (mg/L)

qm = maximum adsorption capacity corresponding to complete monolayer coverage (mg/g)

b= Langmuir constant, qm, and b are determined from the slope and intercept from the Langmuir model.

## Characterization of Adsorbents

Characterization of adsorbents gives information on the surface morphology and the constituent elements in it. SEM and EDX mapping are the techniques used for the characterization.

**SEM (Scanning Electron Microscopy):** The surface morphology and pores in the activated carbon can be accessed by SEM at different magnification. The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The electron interacts with the atoms that make up the sample producing signals that provide information about the sample's surface topography, composition, and other properties such as electrical conductivity.

**EDX (Energy Dispersive X-ray Spectroscopy):** Interaction of an electron beam with a sample produces a variety of emissions, including x-rays. An energy-dispersive (EDX) detector is used to separate the characteristic x-rays of different elements into an energy spectrum, and EDX system software is used to analyze the energy spectrum to determine the abundance of specific elements. EDX can be used to find the chemical composition of materials down to a spot size of a few microns, and to create element composition maps over a much broader raster area. Together, these capabilities provide fundamental compositional information for a wide variety of materials. EDX systems are typically integrated into the SEM instrument.

# CHAPTER TWO: OBJECTIVE

1.
2.

## Objective

The overall objective of this work is to remove arsenic (III) from water by adsorption onto iron oxide/activated carbon composite prepared from Giant Reed.

Specific objectives of this study are:

1. To prepare activated carbon from Giant reed by chemical activation using ZnCl2 as an activating agent.
2. To fabricate iron oxide/activated carbon composite by hydrothermal process.
3. To study the adsorption of arsenic (III) from water using the iron oxide/activated carbon composite by batch technique: Effect of pH, contact time, and adsorbent dosage on the adsorption of arsenic (III).
4. To study the adsorption isotherm for As (III) adsorption by the composite adsorbent.

## Rationale

Groundwater is the main source of drinking water in the Tarai region of Nepal. The groundwater of the Terai region is reported with contamination of a high concentration of arsenic. It has been reported that, about 20 districts where 29% of tube wells have arsenic concentrations exceeding the WHO standard (10 g/L) with approximately 0.5 million people at risk of consuming water with an arsenic concentration > 50 mg/L (Roman Shrestha, 2012). Long-term exposure to arsenic in drinking water can cause increased risks of skin cancer, but also some other cancers, as well as other skin lesions such as hyperkeratosis and pigmentation changes. For this reason, the removal of arsenic from groundwater used for drinking purposes is important to produce safe drinking water for human consumption.

To prevent health problems associated with As, an effective technique for the removal of As from groundwater before using it for drinking purposes is very essential. Different techniques such as chemical precipitation/flocculation, adsorption, ion exchange, reverse osmosis, and electro-dialysis have been used for arsenic removal. Among these, the adsorption technique is the most competitive method, with a number of advantages, such as low cost, high efficiency, and simple operation. Activated carbon is most frequently used as an adsorbent to remove organic pollutants from water due to its high specific surface area. However, plain activated carbon is not very effective for the removal of arsenic from water. Recently, iron modified activated carbons have been employed to enhance arsenic adsorption capacity. Such a combination of iron oxide and AC was demonstrated to be a feasible method to take advantage of the properties of two materials for arsenic adsorption.

Giant reed, an agricultural material is a perennial grass with little economic value. Utilizing Giant Reed canes for the preparation of carbon composite could be a promising approach to produce an efficient, abundant, low-cost adsorbent for As removal. The study focus on the preparation of the activated carbon from Giant Reed stalks by chemically activation using zinc chloride and the compositing resultant AC with iron oxide particles for adsorptive removal of As(III) from water.

# CHAPTER THREE: LITERATURE REVIEW

Activated carbon can be prepared by the physical and chemical activation of carbonaceous materials. During physical activation, the raw material is carbonized first at high temperature, and then it is activated by CO2 or steam. In chemical activation both carbonization and activation take place simultaneously, in which raw material is first impregnated with activating chemicals such as NaOH, ZnCl2, and H3PO4 and then carbonized at the desired temperature. Behaviors of the reagents during chemical activation show different effects on the final product. ZnCl2 is widely used as an activating reagent since it resulted in high surface areas and high yield. Lots of investigation had been carried out on the preparation of AC from various agricultural wastes by chemical activation using zinc chloride as an activating agent. Some of them are described as follows.

Caturla *et al.* (1991) reported that impregnation using ZnCl2 showed dehydration of cellulosic material. On further dehydration, charring and aromatization of carbon sheets occurred making well-developed pore structure during carbonization.

Ahmadpour *et al.* (1997) prepared from macadamia nutshell by chemical activation with potassium hydroxide and zinc chloride. The most important parameter affecting the adsorption capacities of AC are both chemical agents and impregnation ratio. Activated carbon developed through ZnCl2 activation had a higher surface area.

Hu *et al.* (2001) prepared activated carbon from coconut shells by pyrolysis under nitrogen flow at the temperature at 800°C with activating agent/shell ratio (w/w) between 0.25 and 3. The Brunauer–Emmett–Teller (BET) surface area was increased with an increasing ratio of ZnCl2 to shell from 0.25 to 2 and reached a maximum of 2450 m2 /g. It indicated that many micropores were enlarged to mesopores at a higher ratio of activating agent/shell.

Aygun *et al.* (2003) prepared activated carbon from an almond shell, hazelnut shell, walnut shell, and apricot stone using ZnCl2 as an activating agent. Activated carbons from the almond shell, hazelnut shell, and walnut shell have shown the highest surface area at 750°C with 10 hrs of activation. However, for apricot stones, it was obtained with 18 hrs of activation at 800 °C. Pyrolysis temperature and activation time with ZnCl2 influenced the phenol and methylene blue adsorption capacities of the activated carbons produced from hazelnut and walnut shells. Adsorption isotherm data were fitted to both Langmuir and Freundlich models.

Nakagawa *et al.* (2007) prepared two series of activated carbon monoliths (discs) by chemical activation of olive stones with phosphoric acid and zinc chloride to analyze the effect of these activating agents on the porosity of the activated carbon. The experimental results indicate that activation by both chemicals produces a large development of microporosity. However, the differences between the granular and monolithic forms are more noticeable when using phosphoric acid. The different behavior of the two chemicals has been related to their effect on the nature of the precursor along with the impregnation ratio. They concluded that ZnCl2 aided the transformation of mesopores into micropores of activated carbon.

It is clear from the results described in the literature that, ZnCl2 as an activating agent produces high surface area and more porous activated carbons.

In the past decades, iron modified activated carbons have been employed to enhance arsenic adsorption capacity. In these composite adsorbents, iron oxide particles are the active components for arsenic removal whereas AC provides a high surface area and acts as solid support. To improve arsenic adsorption, AC impregnation using a solution of iron salt is most frequently used to synthesize iron oxide doped AC. Removal of arsenic from contaminated water sources by adsorption onto iron oxides, metallic iron, or magnetic iron oxides has been reported by many researchers in the last few decades. Some of them are described below.

Chen *et al.* (2007) found that iron-impregnated activated carbons were very effective in arsenic removal. Iron impregnation by precipitation or iron salt evaporation was also evaluated. The amount of arsenic removed is closely related both to the amount of iron-loaded, and to the dispersion and surface accessibility of this iron within the activated carbon.

Muniz *et al.* (2009) used Fe(III) and Fe(II) to make the iron-doped activated carbons for arsenic removal. For a given method of doping (i.e., constant iron(II) or iron(III) concentration and constant pH), an increase of the Fe content always increased the corresponding arsenic uptake. An increase of the Fe content is useless as long as an excellent dispersion of iron inside the carbon is not achieved.

Rajbhandari *et al.* (2012) employed nanoporous (micro/meso) activated carbons after iron (III) impregnation as adsorbents of arsenite from water samples which were carried out via ferric/NaOH precipitation method. The combination of nanoporous AC and iron offered a better strength of the materials for the higher affinity of arsenate and arsenite ions. The results of arsenic removal using iron impregnated activated demonstrated that the iron impregnated activated carbon can effectively remove toxic arsenic from water samples.

Vitela-Rodriguez *et al.* (2014) prepared activated carbon composite using iron hydro(oxide) nanoparticles for As removal and was found efficient for the removal of arsenic at concentrations lower than 300 mg/L.

Yao *et al.* (2014) examined the adsorption features of activated carbon and the magnetic properties of iron oxides combined in a composite to produce magnetic adsorbent. It demonstrated that the iron impregnated activated carbon can effectively remove arsenic from water. Batch experiments were conducted to study the adsorption behavior of arsenate onto the magnetic carbon adsorbent. The effects of initial solution pH, contact time, adsorbent dosage were investigated. The result showed that the dosage, pH, and contact time affects arsenate removal efficiency.

Lee *et al.* (2015) reported iron oxides incorporated activated carbon for As (v) removal from water by hydrothermal method. Experimental factors such as the nature of iron salt, concentration, pH, and treatment time play key roles in arsenic adsorption capacity. The adsorption mechanisms are associated with electrostatic attraction, ion exchange, and surface complexation. The arsenic adsorption was most efficient when the iron loading content on GAC was ∼6%, further increases in iron content unexpectedly decreased the arsenic adsorption capacity.

Luo *et al*. (2016) developed magnetic Fe3O4-loaded porous carbons composite by a simple one-step synthetic approach using rice husk for removal of arsenate (As(V)). Results showed that the adsorption capacity of the composite was higher at neutral media, and it was enhanced with increasing initial concentration of As (V).

The above studies suggested that iron oxides and metallic iron or magnetic iron oxides doped activated carbon showed high efficiency for the removal of arsenic from water.

Giant reed is lignocellulosic biomass used for the production of fuels and chemicals due to its high biomass productivity and low input requirement. It is a perennial grass that has little economic value and is a lignocellulosic material that gives them the potential to be used as a production for activated carbon. It has been used as a precursor of AC for various applications described below.

Vernersson *et al.* (2002) used Giant Reed Cane as a precursor for activated carbon preparation by phosphoric acid activation under a self-generated atmosphere and found that activated carbons obtained under flowing nitrogen possessed predominant microporous structures and larger ash contents than the samples derived in the self-generated atmosphere.

Sun *et al.* (2012) prepared by grafting amine-group onto Giant Reed activated carbon for the adsorption of hexavalent chromium. When compared with the untreated activated carbon, the modified activated carbon, the composite adsorbent can effectively remove Cr(VI) from aqueous solutions under a wide range of experimental conditions.

Sagehashi *et al.* (2010) studied the applicability of Giant reed as a raw material for the production of adsorbents for the purification of cadmium-contaminated water. Charcoals were prepared from the stalk of the giant reed at various temperatures (400 -700°C) under a nitrogen stream. High removal capacity was observed under a low concentration of cadmium.

A few studies have reported on the carbon composite prepared from activated carbon derived from biowaste for arsenic removal from water. Also, the composite prepared from giant reed activated carbon has not been reported so far for the removal of arsenic from water. Thus, carbon composite prepared from Giant reed as a biowaste material can be a viable adsorbent for arsenic removal from water.

# CHAPTER FOUR: METHODOLOGY

1.
2.

## Materials Used

Giant Reed canes were collected from the wetland of Pulchowk, Lalitpur, Nepal and were washed several times with distilled water and dried in an electric oven at 110°C for 6 hrs. Then, well-dried reed canes were converted to powdered form using an electric grinder and sieved to obtain the particles of uniform size 300 µm. All the stock solutions were prepared in distilled water from LR/AR grade chemicals (Merk/Qualigen) without any further purification. Iron chloride hexahydrate (FeCl3·6H2O) (Samchun Chemicals), ammonium hydroxide (NH4OH, 25% NH3 in water) (Fisher Scientific), arsenic trioxide (As2O3) (G.S. Chemical Testing Lab and Allied Industries) were used for the investigation.

## Instrumentation

The following instruments were used in the entire experimental works.

1. **Horizontal tubular furnace**

The activated carbon was carbonized in a horizontal tubular furnace (Accumax India) with a quartz tube shown in Figure 2.



Figure 2: Horizontal tubular furnace

1. **Spectrophotometer**

The concentration of arsenic was also measured by UV/Vis (CECIL-CE-100) Spectrophotometer.

1. **Scanning Electron Microscopy (SEM)**

Scanning electron microscopy (SEM) characterization was performed with U-8000, Hitachi Co. Ltd. Japan at 5 kV.

1. **pH meter**

pH meter (Hanna pH instrument) was used to measure the pH value of synthetic As (III) solution.

1. **Electric shaker**

A digital rotary shaker was used for agitation of the suspension of arsenic solution and adsorbent**.**

## Preparation of Reagents

1. **Arsenic Stock solution (1000 ppm):** It was prepared by transferring 1.320 g of arsenic III oxides (As2O3; dried for 1 h at 110 °C) into a volumetric flask of 1000 mL and 2 g of sodium hydroxide was added to it and dissolved in a small quantity of water and diluted to volume with water. It corresponds to 1000 mg of As per liter.
2. **0.1M HCl:** It was prepared by dissolving 8.3 mL HCl in distilled water and diluted to 1000 mL
3. **0.1M NaOH:** It was prepared by dissolving 1g sodium hydroxide in distilled water and diluted to 250 mL.
4. **Ammonium Molybdate Solution:** 12.5 g of ammonium heptamolybdate, (NH4)Mo7O24.4H2O, LR grades, qualigens was dissolved in 87.5 ml of distilled water. 140 ml of conc. H2SO4 was added to 200 ml of distilled water continuously. It was cooled and added to the ammonium molybdate solution and diluted to 500 ml.
5. **Potassium Permanganate Solution:** 0.790 g of potassium permanganate (KMnO4, L.R. grade, qualigens) was weighted out accurately and transferred to 250 ml volumetric flask, and volume was made up to mark. It was stored in a dark place. The strength of the solution was 0.1N.
6. **Hydrazine Hydrate:** 2.24 ml of concentrated hydrazine hydrate was diluted up to mark in a 100 ml volumetric flask. The final concentration was 0.5M.

## Preparation of Activated Carbon

Giant Reed dried canes were crushed and made fine powder. About 10 g of powder was separately mixed with ZnCl2 in the ratio of 1:1 by weight and sufficient distilled water was added. Then, the mixture was stirred with a glass rod at 70oC until completely dried and for 24 hrs sample was dried in an oven at 110°C. After drying, the sample was kept in a horizontal tubular furnace and carbonized at 500°C under a continuous nitrogen flow of nitrogen for 3 hrs. Afterward, AC was washed repeatedly with warm distilled water until the pH became neutral. So, the obtained wet AC was dried at 110*°*Cfor further use.

## Preparation of Carbon Composite (iron oxide/ AC composite)

The hydrothermal process was followed for the preparation of activated carbon composite for arsenic removal. The sample was prepared by dissolving 800mg FeCl3.6H2O and 20 mg of PVP in 40 ml of distilled water and 2 ml of ammonia solution was added to this solution with constant stirring for 45 minutes using a magnetic stirrer. The solution containing 100 mg of AC in 20 ml of distilled water and 10 ml of ethanol was added to the former solution. The mixture was then transferred to the autoclave for hydrothermal treatment at 130°C for 3 hrs. After cooling at room temperature, the obtained product was filtered and washed repeatedly with distilled water and ethanol. So the composite adsorbent was then dried in an oven at 30°C for 12 hrs and 80°C for 6 hrs afterward. Now dried product was stored finally for further usage.

## Characterization

The surface morphology of activated carbon and as-synthesized composite adsorbent were studied by scanning electron microscopy (FE-SEM, S-7400, Hitachi, Japan) and Energy Dispersive X-ray analysis (EDX) was also performed using SEM.

**SEM image/EDX**

The surface morphology of the AC and the composite adsorbent was analyzed by scanning electron microscopy (SEM). For the SEM image, a double-sided sticky carbon tape was used and fixed to a flat sample holder. A small amount of the powder was put onto the tape, and the tilted sample holder tapped onto a surface to drop off the excess powder. The images were recorded in U-8000, Hitachi Co. Ltd. Japan at 5kV.

## Arsenic Adsorption Test

The arsenic concentration present in sample water was determined by Molybdenum blue Method. When arsenic as arsenate is treated with ammonium molybdate solution and the resulting hetero polymolybdo arsenate (arsenic molybdate) is reduced with hydrazinium sulfate, a blue soluble complex 'molybdenum blue' is formed. The stable blue color has maximum adsorption at about 840 nm and shows no appreciable change in 24 hr.

For the calibration curve, a standard solution of the arsenic solution of 1mg/L, 2 mg/L, 3 mg/L, and 4 mg/L was prepared. The prepared standard solutions transferred into 25 mL volumetric flasks. To each flask, 4.5 ml sulphuric acid (1.5N), 3 drops (from 1 mL pipette) of potassium permanganate (0.1N), 3 mL ammonium molybdate (0.5%), and 3 mL of hydrazine hydrate (0.5M) solutions were added. Then the volume was made up to the mark by adding distilled water. For maximum complex formation, the above solutions were left for 20 minutes at room temperature. The absorbance of each solution was measured at 840 nm against a blank solution by spectrophotometer.

## Adsorption experiment

### Removal of Arsenic by adsorption (Batch adsorption study)

The adsorption experiments were performed by the batch method. In this method, 0.045 g of composite adsorbent was transferred in 25 mL synthetic water samples containing different concentrations of Arsenic in conical flasks, and the suspension was agitated on a VDRL shaker at 170 rpm at room temperature (30°C). Then the solution was filtered using Whatman 45 filter paper After equilibrium, the suspension was filtered and Arsenic concentration before and after adsorption in the filtrates was analyzed by the molybdenum blue method using UV/Vis) spectrophotometer (CECIL-CE-100) at 840 nm.

The adsorption isotherm study was carried out with different initial concentrations of the arsenic (III) ranging from 2 to 120 mg/L keeping other parameters constant like adsorbent dose 1g/L, contact time 60 min during the experiment.

The milligram of Arsenic per gram of adsorbent, qe (mg/g) adsorbed was calculated by using the following equation (1) and (2).

$q\_{e}\left(mg/g\right)=\frac{\left(C\_{o}-C\_{e}\right)×V}{M}$ (1)

$\% removal=\frac{\left(C\_{o}-C\_{e}\right)×100}{Co}$ (2)

Where,

Co = Initial concentration of Arsenic (mg/L),

Ce= equilibrium concentration of Arsenic (mg/L),

V = Volume of adsorbate solution in liter and

M = Weight of adsorbent in g.

### Comparison of As (III) Adsorption by plain AC and composite adsorbent

0.045 g of plain AC and 0.045 g of the composite adsorbent was added 25 ml As (III) solution (5mg/L) in two bottles each and stirred for 60 min. Each suspension was then filtered and the filtrates were tested for arsenic content.

### Effect of pH

25 ml of Arsenic solution of 5 mg/L was taken in different bottles. The pH of these solutions was adjusted from 2 to 12 by adding 0.1M HCl and 0.1 M NaOH. To each of these solutions, 0.045 g of composite adsorbent were separately added and equilibrated for 3 hrs in an electric shaker at 200 rpm at room temperature (30°C). Then the suspension was filtrated and the concentration of the As (III) in the filtrate was determined by using UV/Vis) spectrophotometer (CECIL-CE-100).

### Effect of contact Time

The effect of contact time was studied at room temperature by taking 0.045 g of composite adsorbent in 25 ml As (III) concentration of 2 mg/L in different bottles. The suspensions were equilibrated in an electric shaker at 200 rpm and varying contact time from 15 min. to 180 min.

### Effect of Adsorbent Dose

The effect of adsorbent dose was studied by varying the composite adsorbent from 1, 1.2, 1.4, 1.6, 1.8, 2.0, 2.2, and 2.4 g/L with a 25 ml solution of As (III) of 5 mg/L concentration. These solutions were equilibrated for 3 hrs in an electric shaker at 200 rpm at room temperature (30°C).

# CHAPTER FIVE: RESULTS AND DISCUSSION

1.
2.

Giant reed, an agricultural material was used as a precursor for the preparation of activated carbon. Activated carbon from Giant Reed canes was prepared by chemical activation with ZnCl2. The AC was composited with iron oxide by a hydrothermal method to enhance the adsorption capacity for arsenic. The AC and AC composite adsorbent were characterized by SEM and EDX techniques. After characterization, the composite adsorbent was applied for removal of arsenic (III) from water by adsorption process. Adsorption of As (III) from water by the composite adsorbent was carried by batch adsorption method.

## Characterization of AC and its Composite

**SEM/EDX studies:** Scanning electron microscopy (SEM) images and EDX spectra of AC and iron oxide/AC composite adsorbent are shown in Figure 3 and Figure 4 respectively.

****

Figure 3: SEM/EDX spectra of Activated Carbon



Figure 4 : SEM/EDX spectra of iron oxide/AC Composite

The SEM images illustrate that the AC shows a smooth surface and AC composite adsorbent contains particle aggregates of iron oxidedepositedon its surface. These particle aggregates are deposited on AC surfaces. Thus, it is suggested that the loading of AC by the iron oxide has been done effectively. The EDX data of AC showed Carbon (55.31%), Oxygen (25.75%), Iron (18.94%) by weight while, AC composite consists of Carbon (43.27%), oxygen (26.25%), and iron (30.48%). EDX of AC composite signified a considerable amount of iron and oxygen in the sample, thus suggesting the presence of iron oxide in AC composite.

## Arsenic adsorption Study

### Calibration Curve

The calibration curve of absorbance as a function of As (III) concentration in mg/L is shown in Figure 5.

Figure 5: Calibration curve for As (III) Adsorption

The concentration As (III) in solution was determined by dividing absorbance to that of the slope. In figure 5, the slope was found to be 0.0155. Hence, Concentration of As (III) in mg/L (Ce) = absorbance/0.0155.

### Comparison of percentage removal of As(III) by adsorption onto plain AC and composite adsorbent

A comparison of percentage removal of As(III) by adsorption onto plain AC and composite adsorbent is shown in Figure 6.

Figure 6: Percentage removal of As(III) by adsorption onto plain AC and composite adsorbent

The result showed that synthesized composite adsorbent removed arsenic around 84% while pure AC removed almost 37%. The result demonstrates that the prepared composite adsorbent is more effective in removing arsenic from water than AC alone.

## Effect of pH

The relative distribution of As(III) in water is influenced by pH and redox conditions (Khraisheh *et al*., 2004). Effect of pH on the percentage removal of As (III) by adsorption onto composite adsorbent is shown in Figure 7.

The percentage of removal increased as the pH increased up to pH 8 then started to decrease. The maximum removal of arsenic ions (~88 %) took place at pH 8.0. Hence, an optimum pH for the removal of As(III) by adsorption onto the composite adsorbent was pH 8.

Figure 7: Effect of pH on the percentage removal of As (III) by adsorption onto a composite adsorbent

The percentage of removal was low at pH 2. It could be attributed to the fact that As species exist as neutrally charged H3AsO3 at low pH which makes it difficult to remove via electrostatic attraction to the positively charged surface. At near neutral pH values of 7 to 9, H3AsO3 could be de-protonated to form anionic species (H3AsO3– and HAsO3–). The neutral H3AsO3 and negatively charged H3AsO3– and HAsO32− were attracted to the positively charged surface of the composite adsorbent. It results in the high uptake of As(III) ion onto the surface of the composite adsorbent. The percentage removal was reduced at higher pH < 9 which may be due to the electrostatic repulsion between H2AsO3– and HAsO32 −species and the negatively charged composite adsorbent (Thakuri *et al*., 2015).

## Effect of Adsorbent Dose

The effect of adsorbent dose on the percentage removal of As (III) by adsorption onto composite adsorbent is shown in Figure 8.

Figure 8: Effect of adsorbent dosage on the percentage removal of As (III) by adsorption onto a composite adsorbent

Increasing adsorbent dose increased the removal of arsenic up to a dose of 1.8 g/L. After 1.8 g/L, the percentage removal of arsenic was insignificant after the addition of adsorbent dose. Therefore, the optimum dose for As removal using AC composite was 1.8 g/L. This may occur because arsenic adsorption takes place in two stages, which are the fast formation of a monolayer followed by a slow plateau stage.

The increase in percentage removal could be attributed to an increase in the adsorptive surface area and the availability of a large number of vacant sites for As adsorption. After a certain dose of adsorbent, the maximum adsorption is attained and hence the amount of ions remains constant even with the further addition of a dose of an adsorbent. It could be attributed to the overcrowding of the adsorbent particles that result in the overlapping or aggregation of the adsorption sites. Similar results were obtained for the removal of As (III) from aqueous solution using Fe (III)-loaded pomegranate waste (Thapa *et al*., 2012).

## Effect of Contact Time

The effect of contact time on the percentage removal of As (III) by adsorption onto composite adsorbent is shown in Figure 9.

Figure 9: Effect of contact time on the percentage removal of As (III) by adsorption onto a composite adsorbent

The percentage removal of As(III) onto the composite adsorbent significantly increased with increasing contact time until a state of equilibrium is reached after 60 min. A further increase in contact time had an insignificant effect on the amount of adsorption. It suggested that optimum contact time for As (III) adsorption onto the composite adsorbent was 60 min. The adsorption rate was increased with time until it reaches equilibrium. This phenomenon is attributed to the fact that a large number of vacant surface sites are available for adsorption at the initial stage, and after a lapse of time, the remaining vacant surface sites are difficult to be occupied due to repulsive forces between the solute molecules on the solid and bulk phases. Similar findings were reported by other researchers (Yao *et al*., 2014).

## Adsorption Isotherm

**For Giant Reed AC composite adsorbent**

The adsorption isotherm indicates how the adsorption molecules distribute between the liquid phase and the solid phase when the adsorption process reaches an equilibrium state. Here, in this study, we analyzed the capacity by using Langmuir and Freundlich models.

The linear form of the *Langmuir* isotherm equation is given as:

 

Where,

Ce = equilibrium concentration (mg/L)

qe = amount adsorbed under equilibrium (mg/L)

qm = maximum adsorption capacity corresponding to complete monolayer coverage (mg/g)

b= Langmuir constant, qm, and b are determined from the slope and intercept from the Langmuir model.

The Langmuir model assumes that maximum adsorption occurs when a saturated monolayer of solute molecules is present on the adsorbent surface, the energy of adsorption is constant and there is no migration of adsorbate molecules in the surface. The Langmuir adsorption isotherm for the removal of As (III) by adsorption onto composite adsorbent is shown in Figure 10.

Whereas, the linear form of *Freundlich* isotherm can be expressed as follows:

 

Where,

K= Freundlich constant

n = adsorption intensity

Freundlich model assumes that the uptake of As(III) ions occur on a heterogeneous surface by multilayer adsorption and the amount of adsorbate adsorbed increases infinitely with an increase in concentration. The Freundlich isotherm for the removal of As (III) by adsorption onto composite adsorbent is shown in Figure 11.

Figure 10: Langmuir Adsorption isotherm for the removal of As (III) by adsorption onto a composite adsorbent

Figure 11 : Freundlich adsorption isotherm for the removal of As (III) by adsorption onto composite adsorbent

In the above graphs (Figure 10 and Figure 11), adsorption of As(III) onto the Giant Reed AC composite adsorbent gave the linear relationship with Langmuir and Freundlich isotherm. The applicability of the isotherm equation was compared by judging coeﬃcients of determination (R2) of Langmuir and Freundlich isotherm plots. The value of the coeﬃcient of determination (R2) of 0.989 for Langmuir isotherm was found to be higher as compared to the Freundlich isotherm (R2) of 0.9404. This suggested that adsorption isotherm data better ﬁtted the Langmuir isotherm. It confirmed the As (III) ions were adsorbed onto the homogeneous surface of the composite adsorbent with monolayer coverage. The monolayer adsorption capacity of Giant Reed AC composite adsorbent for As(III) ion was found to be 16.34 mg/g. Langmuir and Freundlich's parameters are calculated from the slope and intercept of their respective plots.

**Adsorption isotherm for the commercial carbon composite adsorbent**

A Langmuir adsorption isotherm plot of Ce/qe versus Ce for removal of As (III) by adsorption onto commercial AC composite adsorbent is shown in Figure 12.

Figure 12: Langmuir Adsorption isotherm for the removal of As (III) by adsorption onto commercial AC composite adsorbent

Similarly, Freundlich adsorption isotherm for the removal of As (III) by adsorption onto commercial AC composite adsorbent plot is shown in figure 13.

Figure 13: Freundlich adsorption isotherm for the removal of As (III) by adsorption onto commercial AC composite adsorbent

It shows that the commercial composite adsorbent also follows Langmuir isotherm. The monolayer sorption capacity of commercial AC composite adsorbent for As (III) was found to be 7.4 mg/g. Langmuir and Freundlich Parameters for the adsorption of As(III) onto Giant Reed AC composite adsorbent and commercial AC composite adsorbent is shown in Table 1

Table 1: Langmuir and Freundlich Parameters for the adsorption of As (III) onto (Giant Reed AC and Commercial AC) composite adsorbent

|  |  |  |  |
| --- | --- | --- | --- |
|  **Species** | **Adsorbents** | **Langmuir isotherm** | **Freundlich isotherm** |
|  **qm (mg/g)** |  **R2** | **K(mg/g)** |  **R2** |
| As(III) | Giant Reed AC composite adsorbent  | 16.34 |  0.989 |  3.141 |  0.940 |
|  As(III) | Commercial AC composite adsorbent |  7.4 |  0.986 |  2.663 | 0.954 |

On comparison of both composite adsorbents, the maximum adsorption capacity of the composite adsorbent prepared from Giant Reed AC is greater than of commercial AC. It proves that the prepared composite adsorbent from Giant Reed AC possessed higher potential towards the removal of As(III) from the water. So, we can conclude that prepared Giant Reed AC composite can be a good adsorbent for the removal of As(III) from aqueous solution/water.

## Comparison of the Maximum Adsorption Capacity (qm) for As (III) with other adsorbents

The values of maximum adsorption capacity (qm) were also compared to that of other adsorbents. The comparison of maximum adsorption capacity (qm) of the composite adsorbent with other previously reported adsorbents is presented in Table 2.

Table 2: Comparison of the maximum adsorption capacity of the Giant Reed composite adsorbent with other Adsorbents

|  |  |  |
| --- | --- | --- |
| **Adsorbents** | **Maximum adsorbent capacity (qm)** | **References** |
| Fe3O4/AC Magnetic composite | 20.24 mg/g |  Yao et al. (2014) |
| Iron impregnated used tea AC | 6.83 mg/g |  Tahira et al., (2018) |
| Iron oxide/Sugarcane Bagasse AC Magnetic | 6.69 mg/g |  Joshi et al. (2019) |
| Iron oxide/commercial AC composite | 7.40 mg/g | Present Study |
|  Iron oxide/ Giant Reed AC Composite | 16.34 mg/g | Present Study |

The composite adsorbent prepared from Reed AC exhibited a greater As (III) adsorption capacity when compared to other reported adsorbents, such as magnetic nanoparticles obtained from iron impregnated used tea, Sugarcane Bagasse, and commercial AC. The adsorption capacity of the composite adsorbent was greater to iron oxide/commercial AC composite and other composites too. Hence, the result suggested that the prepared composite has greater adsorption capacity towards the removal of As(III) from the water.

# CHAPTER SIX: CONCLUSION

1.

## Conclusion

Activated carbon was prepared by chemical activation using ZnCl2 activating agent. Using resultant AC, the composite adsorbent was prepared via. hydrothermal treatment. The AC and iron oxide/AC composite adsorbent were characterized by SEM/EDX spectroscopy. The composite adsorbent derived from Giant Reed was applied for the adsorption of As (III) from water. The various parameters such as the effect of contact time, pH, and initial metal ion concentration on the adsorption of the metal ions were studied by batch adsorption technique. Adsorption isotherm study in the removal of As (III) by the composite adsorbent was also studied. Adsorption isotherm was also compared to that of commercial AC.

SEM/EDX analysis result of the composite adsorbent showed the formation of iron oxide particles on the surface of AC. Contact time was found equilibrium at 60 minutes and maximum adsorption was favored at pH 8 while the optimum dosage of composite adsorbent was found around 1.8 g/L. Adsorption data of As (III) onto Giant reed AC composite adsorbent as well as commercial AC composite adsorbent followed Langmuir adsorption isotherm model than Freundlich isotherm. The maximum adsorption capacity was found 16.34 mg/g for As (III) onto Giant Reed AC composite adsorbent and 7.40 mg/g onto commercial AC composite adsorbent. It showed the formation of a monolayer of As(III) on the homogenous surface of both composite adsorbents and Giant reed AC composite is an efficient adsorbent for As(III) removal compared to commercial AC composite.

Hence, it can be concluded that AC composite derived from Giant Reed as an agricultural waste could be of low cost, easily available, and an efficient adsorbent for the remediation of arsenic-contaminated water.

**Recommendation:**

* The result of the present study suggests that adsorption on Giant Reed AC composite adsorbent can remove As (III) efficiently. Only ZnCl2 asan activating agentwas used for the chemical activation to prepare activated carbon. However, other activating agents such as acids, salts, and bases can also be used to prepare AC from Giant Reed for further research.
* Not only for adsorption of As (III) ions, the AC and its composite adsorbent can be used for the removal of other harmful chemicals such as dye, heavy metals, etc.
* The study was carried out by batch adsorption process so; the continuous column studies (experimental as well as theoretical) on these systems may be carried out for As (III) adsorption.
* In adsorption studies on Giant Reed AC, regeneration or bio-regeneration or recovery of As (III) may be investigated to apply this approach for industrial application.
* The adsorption kinetics study on the adsorption of As(III) from water using Giant reed AC composite adsorbent can be investigated.

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